MARS GEODESY VIA EARTH-BASED RADIO TRACKING OF MARS LANDERS

Robert D. Kahn, William F. Folkner, Charles Edwards,
Robert Preston, Charles Yoder

Jet Propulsion Laboratory
California institute of Technology
Pasadena, California

The INTERMARSNET mission currently under study by the European Space Agency (ESA) involves the deployment of' four landers on the surface of Mars which will perform seismologic], geodetic, magnetic and meteorological measurements to infer the internal structure of the planet, its figure and rotation state, its magnetic properties, and the atmospheric circulation and weather patterns. While seismology is widely recognized as an invaluable method for the determination of' the interior structure of a planet, emplacement of a network of three or more landers with stable transponders on the surface makes possible a complementary technique for probing the interior of Mars. Simultaneous two-way tracking of radio-frequency carrier signals between a single Earth antenna and several Mars landers enables extremely accurate measurement of the orientation of the planet. By monitoring temporal variations in the planet's orientation, properties of its internal structure ma y be inferred.

The phase of a carrier signal transmitted to an Earth antenna by a lander on Mars has a sinusoidal signature with a period of one Martian day, and amplitude proportional to the distance of the lander from the planet's spin axis. If a carrier signal from two landers is simultaneously recorded at a single site on Earth, the difference phase has a sinusoidal signature with the same period, but with amplitude equal to the maximum projection of the equatorial component of the baseline along the Earth-Mars line of sight (Fig 1). This signature is sensitive to the orientation of Mars. Differenced carrier phase can be measured more accurately than individual carrier phase because large phase deviations incurred by solar plasma density fluctuations are largely common to the two signals. East-West and North-South baselines provide complementary information about Mars orientation variations, so it is desirable to simultaneously track the carrier phase from three non-colinear landers.

Previous covariance analyses (Ref. 1) showed that sub-decimeter determination of Mars precession, nutation and length-of-day variation is possible via simultaneous Earth-based tracking of a network of Mars landers (a decimeter at the surface of Mars corresponds to a rotation of 6 mas). In those analyses, the orientation of Mars was modelled as comprising linear terms to account for precession, and annual and semi-annual period sinusoidal nutation terms for each angular component of the pole position, Measurement of these parameters provides indirect information about the principal moments of' inertia of Mars, and therefore the planet's internal structure..

In a new analysis, rather than directly estimating the amplitudes of many nutation terms, we employ a simple physical model for the Mars interior and estimate three key physical parameters which affect the precession and nutation amplitudes. The three parameters are C, the polar principal moment of inertia, F, a core flattening factor, and σ_0, the free angular rota t ion rate of the fluid core.

listed in Table 1 is a set of covariance analysis assumptions. in this covariance analysis, three landers are simultaneously tracked at a single Earth station for several hours once per week over a period of two years. The estimated parameters include the Mars lander locations, the parameters C, F, and σ_0, the obliquity and ecliptic longitude of the Mars pole, and Mars UT1 and X- and Y-polar motion, Mars UT1 and X- and Y- polar motion arc estimated independently for each pass. The data acquired is carrier phase, differenced between pairs of landers; the carrier signal is assumed to be at S-Band (2.3 GHz). The carrier phase data are two-way, i.e. each spacecraft coherently transponds an uplink signal originating at the Earth tracking station. Because signals between the three Mars landers and the single Earth station traverse regions of interplanetary space which are separated by hundreds of kilometers, phase fluctuations introduced by charged particles in the solar wind do not cancel completely when the signals are difference. The error on the difference phase measurement due to the solar plasma can be estimated using an expression for the power spectrum of plasma-induced phase fluctuations (Ref. 2). For this covariance analysis, the estimated two-way differenced phase error is 3.6 mm (0.03 cycles) for S-minute averages. In addition, the differenced signals are also corrupted by Fluctuations in the delays through the lander transponders, which may vary significantly ***over*** the course of hours as the local temperature changes, To account for this, the phase delay through each lander's transponder is modeled as a random walk whose uncertainty grows by 2 cm per day.

The results of the covariance analysis are displayed in Table 2. The 1-o error estimates of the polar moment of inertia, the flattening factor, and the core free rotation rate are sufficiently accurate to provide meaningful estimates of the mean density of the mantle, mean density of the core, and the radius of the core. Weekly measurement of UT1 to 5.2E-06 degrees (equivalent to 31 cm at the planet's surface) will allow monitoring of seasonal cycling of CO_2 between gaseous and solid states as well as the global angular momentum exchange between the planet and its atmosphere. Measurement of polar motion with 1.2E-06 deg accuracy may enable detection of polar motion variations due to asymmetry of polar ice cap deposition.

Additional covariance analyses have been performed to study the ability to estimate Mars geophysical parameters as a function of the assumed transponder delay stability, and as a function of the number of landers tracked. The uncertainty in the parameter estimates is ' roughly proportional to the assumed transponder stability and is seriously degraded when fewer than three landers are tracked. Full results will be presented in the paper.

ACKNOWLEDGMENT

The research described in this abstract was carried out by the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

References:

1. Edwards, C. D., R. D. Kahn, W, M. Folkner, and R. A. Preston, "Mars Planetary Geodesy Using Earth-Based Observations of Mars Landers", Paper AIAA 92-4666, AIAA/AAS Astrodynamics Conference, Hilton Head, South Carolina, August 10-12, 1992.

2. Armstrong, J. and R, Woo, "spacecraft Radio Scattering observations of the Power Spectrum of Electron Density Fluctuations in the Solar Wind", *J, Geophys. Res.,* Vol. 84, No. Al 2, pp. 7288-7296, Dec. 1, 1979.

Figure 1. If carrier phase from two Mars landers along a baseline b is simultaneously tracked at a single Earth station, the amplitude, a, of the sinusoidal differenced carrier phase signature is equal to the maximum projection of the equatorial component, b_e, on to the Earth-Mars line of sight.

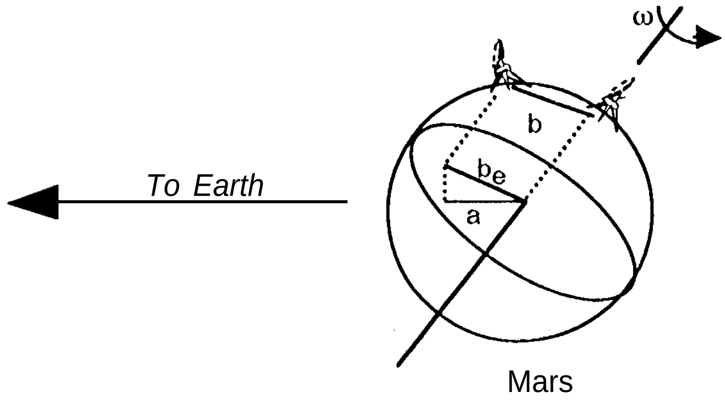

Table 1. Covariance analysis assumptions

Transmitted Frequency: S-Band (2.3 GHz)

Two-Way Differenced Phase Data Weight: 3.6 mm (S-rein average)

Lander Locations

	Latitude	Longitude
Lander 1	0	0
1-a rider 2	0	20 E
Lander 3	20 N	0

Estimated Parameters

Parameter	Nominal Value	A Priori σ
Polar moment of inertia	0.365	0.5
Core flattening factor	0.070	0.5
Core free rotat ion rate	1.5 deg/day	1.0 deg/day
Pole obliquity	25.19 deg	1.0 deg
Pole ecliptic longitude	-98.03 deg	1.0 deg
lander locations		1000.0” km
Mars UT1 (est. each pass)	0 deg	1.0 deg
Mars polar motion x (est. each pass)	0 deg	1.0 deg
Mars polar motion y (est. each pass)	0 deg	1.0 deg

lander transponder delays (random walk with 75 ps growth over 24 hr).

Table 2. Covariance analysis results

Parameter	1-σ error on parameter estimate
Polar moment of inertia	0.00038
Core flattening factor	0.011
Core free rotation rate	0.021 deg/day
Pole obliquity	5.3E-07 deg
Pole ecliptic longitude	1.0E-05 deg
Mars UT1	5.2E-06 deg
Mars polar motion x	1.8E-06 deg
Mars polar motion y	1.2E-06 deg